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THE METEOROLOGICAL MAGAZINE

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NOTICES

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METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 89, No. 1,061, DECEMBER 1960

HEADQUARTERS RE-ORGANIZATION

By The DIRECTOR-GENERAL

In 1957, as a result of the report of the Brabazon Committee, the structure of the directorate of the Meteorological Office was considerably changed. In 1961 the Headquarters sections of the Office, which for many years have been dispersed between London, Dunstable and Harrow, will come together at Bracknell. This has given an opportunity to reconsider the Headquarters organization in the light of experience gained in the last three years and the changes that are taking place in meteorology both as a science and a profession.

The outstanding feature of the Brabazon re-organization was the recognition of the dual role of the Office, namely, to provide meteorological services on a national scale and to act as the primary scientific institution of this country for the advancement of the science of the atmosphere, by the creation of two Directorates, of Services and Research, respectively. This fundamental division of responsibility has been maintained in the new structure. The Director of Research, Dr. R. C. Sutcliffe, F.R.S., has now become the senior Director and Dr. A. C. Best has succeeded Dr. Stagg as Director of Services.

This change necessarily means that the Director of Research, as deputy to the Director-General, has additional administrative and general policy responsibilities. A new deputy-director post has therefore been introduced into the research directorate. Mr. J. S. Sawyer has relinquished his personal post of Chief Forecasting Research Officer to become Deputy Director in charge of Dynamical Research. Other changes within the Research Directorate are that in future all public inquiries relating to areas outside the United Kingdom will be handled by Climatological Services (M.O.3), and the library and the editing sections will no longer be attached to Climatological Research (M.O.13), which, however, will absorb the long-range forecasting research unit from Synoptic Research (M.O.12). The last-named change reflects the view that long-range forecasting is more intimately related to the general circulation of the atmosphere than to ordinary synoptic meteorology.

The changes in the Directorate of Services reflect two features which have become prominent since the meetings of Lord Brabazon's Committee. In recent years there has been a continuing growth in demands for services not specifically related to aviation, and also something of a revolution in the handling and processing of the vast amount of information reaching the meteorological services. To meet the first situation, the administration of both civil and

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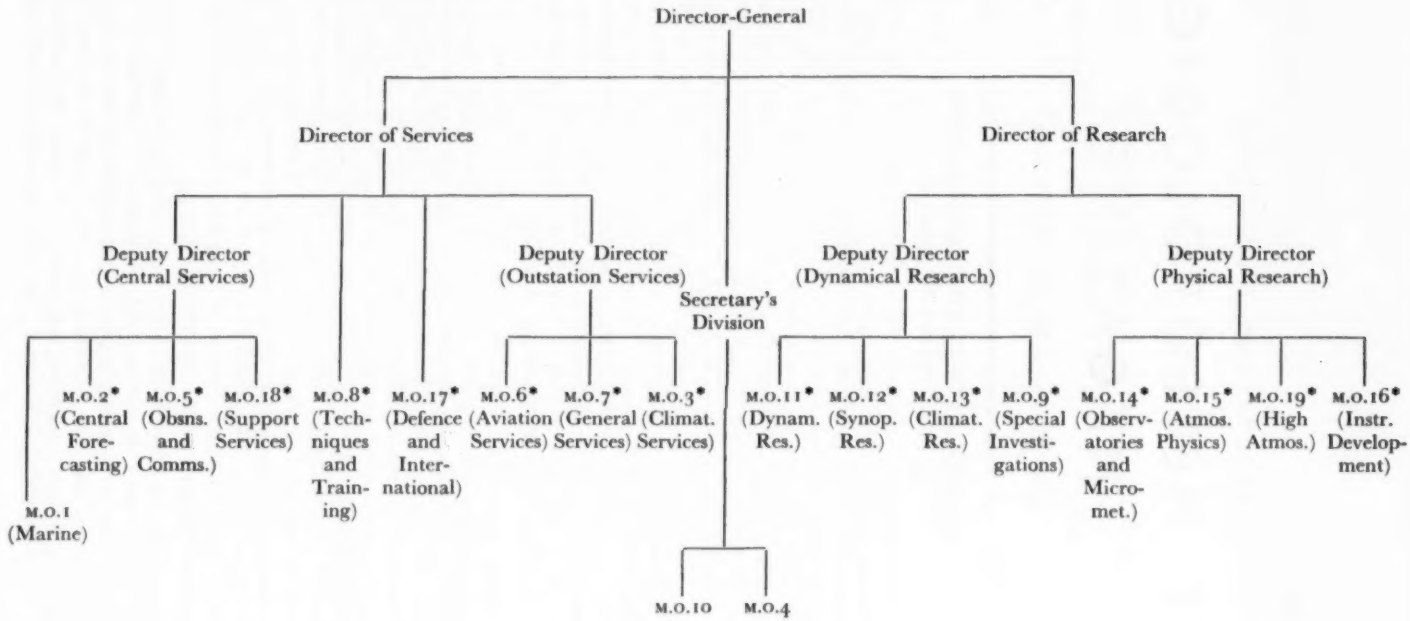

* Assistant Directorates

military meteorological services is now combined under one Assistant Director and, to reduce the load to manageable dimensions, international work connected with civil aviation meteorology has been transferred to the Assistant Director in charge of Defence and International matters (M.O.17) who already handles relations with the World Meteorological Organization. In future this Assistant Director will report to the Director of Services, but he will continue to assist the Director-General when the latter acts as the United Kingdom Permanent Representative with the World Meteorological Organization or in his personal capacity as a member of the Executive Committee of the World Meteorological Organization.

A new post, that of Assistant Director (General Services) will cover all non-aviation matters outside climatology. The major interests of this assistant directorate will lie in the agricultural services and in the Weather Information Centres, of which three are now in existence, in London, Glasgow and Manchester. The Assistant Director (Climatological Services) takes over all climatological inquiries, including world climatology (as noted above) and marine climatology. The Marine Superintendent will concentrate upon the management of the Ocean Weather Fleet, the collection of data from ships, control of the Port Meteorological Officers, editing of the *Marine Observer* and the preparation of those of the publications of the Office that deal with the oceans. He and his Nautical Officer staff will act as advisers to the whole Office on problems calling for a seaman's professional knowledge of maritime matters.

The problems of data handling and processing have now grown so large and are so specialized that it has been thought advisable to create a new Assistant Directorate, called Support Services, to deal with these and other cognate matters, including the Library, Archives and all editorial and cartographical work for official publications. It is clear that in the near future the collection, analysis and storage of meteorological data must become part of an integrated system depending more than ever on machines. The problem of specifying such a system has been under intensive study in the Office for some time.

The new organization is shown in the diagram on page 310. The reunion of parts of the Office that have been separated geographically for so many years has made possible a closer integration and a more rational division of duties. It cannot be too strongly emphasized that the Meteorological Office is a single entity dedicated to the task of advancing the science of the atmosphere in both its pure and applied aspects. The new arrangement, it is hoped, will enable it to function efficiently and harmoniously in its new home.

551.509.615

RECENT WORK ON THE ARTIFICIAL DISPERSAL OF FOG

By K. H. STEWART, M.A., Ph.D.

Introduction.—The idea of clearing fog artificially is very attractive and many methods of bringing it about have been suggested. A rough quantitative examination soon shows that no method so far proposed offers any prospect of clearing large areas for long periods except at enormous cost. The only likely application is to the clearing of small areas where the economic benefit would be high; the obvious example is an aerodrome runway, though railway marshalling yards and rocket test sites have also been suggested. It was shown

during the 1939–45 war that it was technically possible to produce useful clearances on runways by the thermal method ("FIDO"), though the cost was high. Since the war there has been much discussion of the possibility of using FIDO for civil aircraft, and the economic possibilities of an installation at London Airport have been examined carefully. A final decision to build such an installation has always been postponed to await the results of trials of the various improvements that have been suggested from time to time. A full-scale system incorporating these improvements has been built at Marham in the last few years to meet a Royal Air Force requirement and tests of it began in the winter of 1959–60. It seems clear that any fog dispersal system which was markedly cheaper than FIDO would be eagerly adopted by civil aviation in this country. The requirements of the Royal Air Force are less certain; it is understood that the operational requirement for a FIDO installation has recently been cancelled, presumably because of the development of automatic landing devices, but there can be little doubt that any really cheap and effective method of fog disperal would be of interest to service as well as civil aviation.

In America there was a good deal of work on fog dispersal by thermal and other methods in the late 1940s, but work then came to a standstill for many years, following some rather unsuccessful trials of the thermal method using inadequate equipment. In 1959 there was a revival of interest in the subject and the Geophysics Research Directorate began experiments to test various methods of fog dispersal at Arcata, California. The first results of this work and plans for its continuation were discussed at a conference held in Boston in January 1960. It seemed that the work was inspired more by a feeling that fog dispersal had been neglected and was now a field ripe for study than by any urgent demand for a method of clearing fog.

The general background to fog dispersal work is thus one of considerable potential "user interest", though immediate active interest has been dulled by realization of the difficulties and knowledge of the great cost of the one well tried method. With this background, this paper is intended to survey recent work, report on some trials carried out by the Meteorological Office and discuss possible developments.

Recent work in Britain

FIDO.—The development of FIDO has been carried on by the Ministry of Supply (now of Aviation). The main development since the war has been the introduction of high-pressure burners and automatic igniting devices. These were tried out at the Royal Aircraft Establishment Farnborough and have been used in the trial installation at Marham. This installation contains three parallel 900-yard burner lines which will enable realistic tests of the heat distribution and effects on visibility to be made but which will not clear enough runway for full-scale flight trials.

Considerable trouble was experienced with corrosion and blocking of pipes and burners, but after modifications satisfactory burning was achieved late in 1959 and tests were begun. These are to concentrate on the measurement of heat distribution in clear air, but one burn in fog has confirmed that satisfactory clearance can be produced. Further estimates of the economics of an installation at London Airport are to be made when the trials are complete.

Surface-active chemicals.—Between 1955 and 1958 work was done at Battersea Polytechnic under a Ministry of Supply contract, based on the idea that small amounts of "surface-active" chemicals could profoundly affect the short-range

forces between drops and so increase the probability that colliding or nearly colliding drops would coalesce. The theoretical basis of the work was never very clear but laboratory experiments showed that some increase in coalescence efficiency could be produced. In natural fog the collision frequency is so low that an increase in coalescence efficiency is unlikely to affect the rate of precipitation much. Despite this unpromising outlook the Battersea group made several field trials in which fogs were sprayed with surface-active solutions from aircraft. No effects attributable to the spray were observed. Work on this method has now ceased in this country.

Hygroscopic chemicals.—The possibility of dissipating fog by absorbing water vapour with hygroscopic droplets was studied in detail about 25 years ago by Houghton and Radford and in several practical trials they were able to produce cleared regions some 600 metres long by 40 metres wide by 20 metres high by spraying quantities of the order of one ton of calcium chloride solution into the fog. The method was not developed further because of the large quantity of the chemical required, its corrosive nature, and the difficulty of distributing it over the required volume. The method has recently been examined in the Meteorological Office and it seemed that by making the best use of modern spraying techniques it might be possible to achieve fog clearance with much smaller quantities of chemical. It was calculated that if droplets of diameter about 70 microns could be released at the top of a 100-metre-thick layer of fog, about 10gm m^{-2} of solution would be needed to clear the fog. The results of calculations on the growth of droplets and a discussion of the best hygroscopic material to use are reproduced in Appendixes 1 and 2 (pages 316, 317).

Practical trials of this method were organized at Cardington late in 1958. The trials are described in Appendix 3 (page 318) but the results can be summarized as very inconclusive. The spraying equipment gave only about one fifth of the expected output and no visible results were obtained when, as planned, the sprayer was moved through the fog at 10–15 m.p.h. By keeping the sprayer stationary and relying on the wind (usually 2–3 m.p.h.) to distribute the spray a greater area concentration of spray was obtained and on all three occasions of dense fog and steady conditions a small (30–50 per cent) but definite improvement in visibility was obtained. On three other occasions with thinner and less constant fog the results of spraying were indistinguishable from the natural variations in fog density.

Techniques were developed for sampling the spray deposited on the ground and measuring the proportions of water and of hygroscopic material, so that the amount of water absorbed by the spray could be measured and compared with theory, but before these could be applied on a useful scale the spraying equipment (which had been borrowed) had to be returned and trials were ended.

Recent work in the United States of America.—This survey is based on the papers and discussions at the "First Fog Research and Modification Planning Session" held in Boston, Mass., on 25 and 26 January 1960 by the Aerophysics Laboratory, Geophysics Research Directorate.

A site at Arcata, California, has been provided with instruments for measuring many different quantities in fog, both at ground level and on a tower and balloon. Most of the instruments are duplicated, at a "test" site and a "control" one. In general the equipment is roughly equivalent to that at the Meteorological Office's Cardington site in so far as the measurement of basic meteorological parameters is concerned, but it includes instruments for more elaborate

measurements not yet attempted at Cardington—liquid water content, drop size distribution, condensation nuclei and electrical properties. American instruments for these measurements are being developed along lines familiar in this country and are encountering familiar difficulties; they are not yet giving fully satisfactory results.

The site is equipped with two means of distributing materials in fog, a light aircraft fitted with a spray boom and a ground-mounted motor-driven fan (a standard "frost-prevention fan"); the fan has been observed to blow a plume of powder or spray to a height of 800 feet in calm conditions and to 200 feet in a 15-knot wind.

The equipment was built up during 1959 and some preliminary tests of fog dispersal methods were made during the 1959 fog season (July–October). These were on a very small scale because fog was infrequent and equipment not ready, but it is planned to continue and extend them for at least one more season. The methods tried were:

(*a*) Heat from a jet engine exhaust. No tests were made in fog, but the heat distribution was measured in clear air.

(*b*) Hygroscopic chemical ($Ca\ Cl_2$) blown up from the ground by the fan. Only one trial was made; the amount of chemical added was not measured and no definite results were observed.

(*c*) Surface-active solution ("benzalkonium chloride") sprayed from the aircraft. Two trials were made, with no visible results, though in each case the drop size distribution in the fog changed after spraying.

Trials of these methods will continue and, in addition, work is planned on the use of finely divided carbon (to absorb solar heat), the mechanical sweeping action of falling drops and the effects of electric fields on coalescence processes. The facilities of the Arcata site are being offered to any group wishing to make experiments on fog clearance.

There was fairly widespread criticism of the Arcata trials on two grounds; first, that the site was not a suitable one since the fog, in a transition zone between sea and land, was not usually in a steady state; second, that many of the trials were being undertaken without adequate calculation of the effects to be expected and that some of the experimenters seemed to rely on statistical examination of results to compensate for lack of understanding of the physical processes at work.

If any of the methods being tried at Arcata show promise it seems that a further stage of trial with the chosen method applied on a bigger scale and under closer quantitative control will be necessary before a good assessment of the engineering and economic problems of a full scale installation can be made.

Apart from the Arcata trials there were reports to the Boston conference on work on the use of sound waves to precipitate fog—this was shown to be very unpromising—and on the effects of electric fields. Numerical computations of the hydrodynamic and electrical forces between drops falling in an electric field showed that the collection efficiencies could be significantly affected by fields between 1 and 10 volts per centimetre, particularly for small drops. The calculations had not been carried to the point of estimating the effects of these changes in collection efficiency on the stability of fogs (but the effects seem unlikely to be at all large). Dr. Vonnegut reported his work on the production of artificial fields near the ground by the introduction of a sheet of space charge from a

corona-discharging wire. It is quite easy to produce artificial fields of the order of 10 volts per centimetre over large areas and this opens up interesting possibilities (which have not yet been followed up) both of studying the direct effects of fields on fog and of "suspending" artificially-charged drops in the artificial field so that they can collect water, either by collision or by hygroscopic action, over longer periods than normal drops.

Work on supercooled fogs.—The work mentioned so far has been concerned with "warm" fogs, above 0°C. Fogs of supercooled water drops are much easier to modify artificially because they can be made unstable by the addition of ice nuclei. Work on fog clearance by this method has been reported from Switzerland (silver iodide) France (liquid propane) and the United States (solid carbon dioxide), but in all cases trials have been on a small scale and reports of results rather sketchy. The silver iodide method would have little application in Great Britain because it will not work at temperatures above −5°C and few fogs here are colder than that. The other methods, which may work up to −1°C, might be of more use, though French reports suggest that the usual effect is an approximate doubling of the visibility rather than complete clearance of the fog. This would obviously limit the usefulness of the method.

Possible future work on warm fogs.—Methods for the artificial dispersal of fog have been reviewed by Brunt,[1] Houghton and Radford[2] and Junge,[3] and there is no need to repeat here these authors' examination of many unsound or impracticable suggestions. It is striking that the three methods selected by Junge as having some prospect of success are just those selected by the other authors twenty years earlier, namely the thermal method, the hygroscopic chemical method and the use of an electrically charged spray to collect and carry down the fog drops. There was no serious disagreement with this view at the Boston conference.

These three methods are in very different stages of development. The thermal method has been used operationally and the costs and behaviour of a full-scale installation can be predicted reasonably accurately. The hygroscopic chemical method has undergone small-scale field trials with some success but has not been tried operationally; the physical principles of the method are thoroughly understood and allow order-of-magnitude estimates to be made of the quantities of material required for success, but more exact estimates depend on the exact performance of the equipment used and the details of wind, temperature, and humidity structure in the fog and could only reasonably be made on the basis of further field trials. The use of an electrically charged spray is based on a sound physical principle but the quantitative theory of the effect is complicated and there is a need for further calculations and small-scale experiments before even the order of magnitude of the effects to be expected in large-scale operations could be predicted with much confidence.

The development of the thermal method is now an engineering matter, outside the scope of the Meteorological Office. The hygroscopic chemical method is still in much the same state as it was when Houghton and Radfords' work ended; the short series of trials in 1958 added little to our knowledge because of the low output of the spray equipment. The obvious line of development would be to develop equipment capable of delivering at least 10 gm m^{-2} of solution in the form of drops between 50 and 100 microns in diameter over an area at least 50 × 400 square metres in a time of the order of one minute (this corresponds to a spray output of 40 gallons per minute) and to study the effects

of this spray in fog. No smaller scale of experiment is likely to produce obvious clearances in fog and it is suggested that it is not really appropriate to hand over development from scientist to engineer until such clearances have been produced and their behaviour studied; although the basic physics of the process is well established the meteorology, that is, the effects of wind, vertical motion, horizontal diffusion and possibly radiation cannot easily be predicted without trial.

The electrically charged spray method has many uncertainties but it does seem to offer the possibility of a much cheaper method of clearing fog than the other two principles. Its development would have to proceed in two stages, first a laboratory and field study of the production of charged drops and the rates at which they lose charge and collect other drops in fog, and second, after consideration of the results obtained, the design and trial of an installation big enough to produce visible clearances in fog. This installation might take many forms; the charged spray might be delivered from an aircraft or released from the ground and carried up by a fan or by an artificial electric field; the spray might be of liquid or solid, and might be made of hygroscopic material to reinforce the electric collection effect. It is clear that the first stage must be the small-scale study of the collection process. In outline the programme of work suggested is:

(*a*) Measurement of charges on natural fog drops.

(*b*) Production of spray drops with uniform size and charge.

(*c*) Measurement of water and charge collected by these drops when falling through fog, in a laboratory fog, in natural fog near ground level and, finally, in natural fog, with spray released from a tower or balloon.

The techniques for these measurements do not seem unduly difficult, but the programme outlined is a fairly substantial one. The scientific interest of this work is greater than that of work on hygroscopic sprays and, in the long term, its practical importance might also be greater.

Appendix 1

Growth of solution droplets falling through a saturated atmosphere

The equation for the growth of a droplet was taken in the simplified form $r\,dr/dt = A\,\Delta p/p$, where r is the radius of the droplet, $\Delta p/p$ the fractional vapour pressure lowering by the solute and A a constant whose value has been taken as 55 μ^2/sec, appropriate to 0°C.[4] At 10°C A is 83 μ^2/sec and the rate of growth of droplets would be quicker than calculated below. $\Delta p/p$, of course, depends on the concentration of solute and hence on the size of drop. It was plotted, as a

TABLE I

		Height h (metres)					
		0	1	5	20	50	100
NH_4NO_3 initial diam. 50 μ	t (sec)	0	11·0	40·0	116·0	220·0	365·0
	$\sigma^3 - 1$	0	0·7	2·1	5·0	7·8	11·6
	$d\sigma^3/dh$	0·77	0·50	0·27	0·13	0·07	0·05
NH_4NO_3 initial diam. 100 μ	t (sec)	0	3·0	14·0	54·0	110·0	192·0
	$\sigma^3 - 1$	0	0·05	0·2	0·9	1·6	2·4
	$d\sigma^3/dh$	0·048	0·045	0·039	0·030	0·020	0·015
$Ca\,Cl_2$ initial diam. 50 μ	t (sec)	0	10·0	37·0	116·0	222·0	370·0
	$\sigma^3 - 1$	0	1·0	2·8	5·0	7·0	9·7
	$d\sigma^3/dh$	1·62	0·62	0·21	0·10	0·06	0·04
$Ca\,Cl_2$ initial diam. 100 μ	t (sec)	0	3·0	14·0	49·0	111·0	190·0
	$\sigma^3 - 1$	0	0·10	0·4	1·1	1·9	2·8
	$d\sigma^3/dh$	0·10	0·08	0·051	0·028	0·018	0·010

function of σ, the dilution of an originally saturated drop, from data given by Landolt-Bornstein[5] for ammonium nitrate and by the *International Critical Tables*[6] for calcium chloride. The growth equation was then integrated graphically for two initial diameters and the distance of fall from the origin was also found, using the expression $V = 3041\ d^2$ (V in cm/sec, d in mm) for the terminal velocity. Results are given in Table I showing the time taken to fall various heights (t), the total water absorbed for unit volume of original drop ($\sigma^3 - 1$) and the rate of absorption for unit distance of fall.

Appendix 2

Properties of hygroscopic materials

The best measure of the merit of different materials depends on the way they will be used. If the cost of distributing the material is high (for example, if aircraft are used) it will be desirable to have the absorption of water vapour per unit mass (or possibly volume) of saturated solution as high as possible. If distribution is cheap, then high absorption in terms of cost of solute would be sought. Moreover, the absorption by different substances varies differently with dilution of the solution and relative humidity of the surroundings, so that the choice of material will depend on the degree of dilution it is hoped to reach (a function of size of drop and height of release) and on the final relative humidity to be obtained.

The simplest figure of merit is obtained by dividing the number of grams of the substance that will dissolve in one litre of water by the molecular weight and multiplying by the number of ions formed in dilute solution. This gives a figure proportional to the lowering of vapour pressure (relative to that of pure water) over a saturated solution which has absorbed a given (large) number of times its own volume of water, and therefore indicates the efficiency of the material if absorption is able to proceed for a long time in a saturated atmosphere. In practice, the spray drops would not reach a high enough dilution for the laws of dilute solutions to apply at all closely, and the figures of merit suggested above ought to be multiplied by the "activity coefficient" appropriate to the material, temperature and final concentration concerned. It happens that ammonium nitrate and calcium chloride have particularly low and high activity coefficients, respectively, so that although their figures of merit given in Table II differ by a factor of two, their actual efficiency as calculated from experimental vapour pressure data in Table I, is not very different. For most other materials the activity coefficients are closer to unity and the figures of merit given below would measure their actual efficiencies more closely.

TABLE II

Material	Solubility at 10°C (gm/1000 gm water)	Molecular weight	"Figure of merit"
NH_4NO_3	1470	80	36·8
$CaCl_2$	650	110	17·7
NaCl	357	59	12·1
$MgCl_2$	535	94	17·1
$NaNO_3$	805	85	19·0
K_2CO_3	1100	138	24·0
$KC_2H_3O_2$ (Acetate)	2340	98	48·0
$Ca(NO_3)_2$	1020	164	18·7

Appendix 3

Attempts to clear fog by spraying ammonium nitrate solution

The trials were carried out at Cardington, using a "mobile tree sprayer" lent by the National Institute of Agricultural Engineering (NIAE). This machine has a 70 h.p. car engine driving a centrifugal blower which delivers 7000 cubic feet of air per minute and a pump which feeds the solution to be sprayed into the airstream through suitable nozzles. The spray is produced in a fan-shaped sheet; in typical conditions at Cardington this had a horizontal spread of about 25 metres and reached a height of about 30 metres. The rate of delivery of the solution used at Cardington was measured to be about 25 litres per minute. Measurements by the NIAE gave a mass median drop diameter of 130 microns; attempts to measure drop size distribution at Cardington were not very successful, but indicated a larger mass median diameter, between 150 and 200 microns. This larger size may have been due to the properties of the solution being sprayed. This was a saturated solution of commercial ammonium nitrate made by adding 300 kilograms of the salt to 250 kilograms of water.

Apart from a few trials in clear air to measure the spread of the spray and the drop size distribution, the following trials were made in fog. With one exception they were made between about 0800 and 1000 GMT.

14 *November* 1958.—Three runs were made, in which the sprayer was towed along a 400-yard track at about 8 m.p.h. The visibility varied between 100 and 300 yards at the time of the first run and had increased to 400 yards by the time of the third. Some observers reported temporary improvements in visibility after the spray runs, but these may well have been natural variations.

21 *November*.—Two runs were made, as before, but the fog was thinning rapidly during the trial and no significant changes were observed.

4 *December*.—By this time it had been realized that the output of spray was much lower than expected and that the only hope of achieving the concentration indicated by the calculations of Appendix 1 was to keep the sprayer stationary. In winds of 2–3 m.p.h. the desired concentration would then be obtained in a lane downwind of the sprayer and one might look for improvements in visibility there.

Thick fog formed in the evening. Small electric lamps were set out downwind of the sprayer. Before and after spraying they could be seen at a range of 150 yards. The sprayer was run for two periods of about three minutes and during each the range of the lamps increased to about 220 yards. The "surface wind" during these runs was 5–7 knots.

15 *December*.—Three runs were made, with the sprayer stationary. During the first two the visibility was 130 yards and the wind 3–5 knots. For the third the visibility and wind had both increased considerably and no significant results were observed. During the first two runs, each of three minutes, there was a small but definite improvement in visibility, to about 200 yards, downwind of the sprayer, with a very noticeable decrease in visibility shortly after the sprayer was turned off.

23 *December*.—Two runs were made, with the sprayer stationary, in a wind varying between 4 and 8 knots. In the first run the visibility was fluctuating between 200 and 400 yards. During the three-minute spraying period a marked reduction in visibility to about 150 yards was observed downwind of the sprayer. The second run was a short one of only 20 seconds mainly for the

purpose of collecting drop samples, and no appreciable changes in visibility were observed.

This short series of trials suggests that it is just possible in favourable conditions (light but steady wind and thick, constant fog) to produce appreciable clearance of fog by spraying ammonium nitrate solution from the NIAE machine. To be certain of producing a readily visible clearance in a reasonably wide range of conditions a machine with several times the output and a better drop size distribution would be required. To be certain of observing the extent and duration of any clearances produced, with reasonable precision, a larger team of observers than the three to five available at Cardington, or a set of recording meters, would be required.

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551.513:061.4

REPRESENTATION OF THE GENERAL ATMOSPHERIC CIRCULATION: AN EXHIBIT IN THE ROYAL SOCIETY EXHIBITION

By H. H. LAMB, M.A.

The Royal Society Tercentenary Celebrations included an Exhibition from 25 to 29 July 1960 representative of a wide variety of fields of scientific endeavour. Dr. G. E. R. Deacon F.R.S., Director of the National Institute of Oceanography, who was responsible for the organization of a stand in the Exhibition, invited the collaboration of the Meteorological Office in order to widen the scope of the exhibit to include as much as possible of the earth sciences which are thoroughly interwoven. The purpose was to indicate the wealth of interesting problems in these subjects and a few of the instruments and observational techniques by which our knowledge is built up.

Of the fifteen different stands in the Exhibition that devoted to the "Physics of the Earth, Ocean and Atmosphere" was amongst the four which attracted the largest numbers of visitors. Desires were expressed that meteorology should be taught in physics courses and that the forms of representation of the large-scale circulation used in the exhibit should be made widely available, published in books and printed by map-makers.

Instruments shown included the radio-sonde and Cintel radio-sonde recorder, a neutrally buoyant float ("Pinger") which emits acoustic signals for measuring currents in the deep ocean, a micro-seismograph used for detecting the vibrations caused by storm waves on the ocean some thousand miles distant and a corer for obtaining ocean-bottom cores. A weather ship and past and present oceanographical research vessels were illustrated by models and pictures.

The main display panel consisted of a cross-section (Plate I) through the atmosphere from the North Pole to the South Pole in January, up to a height of

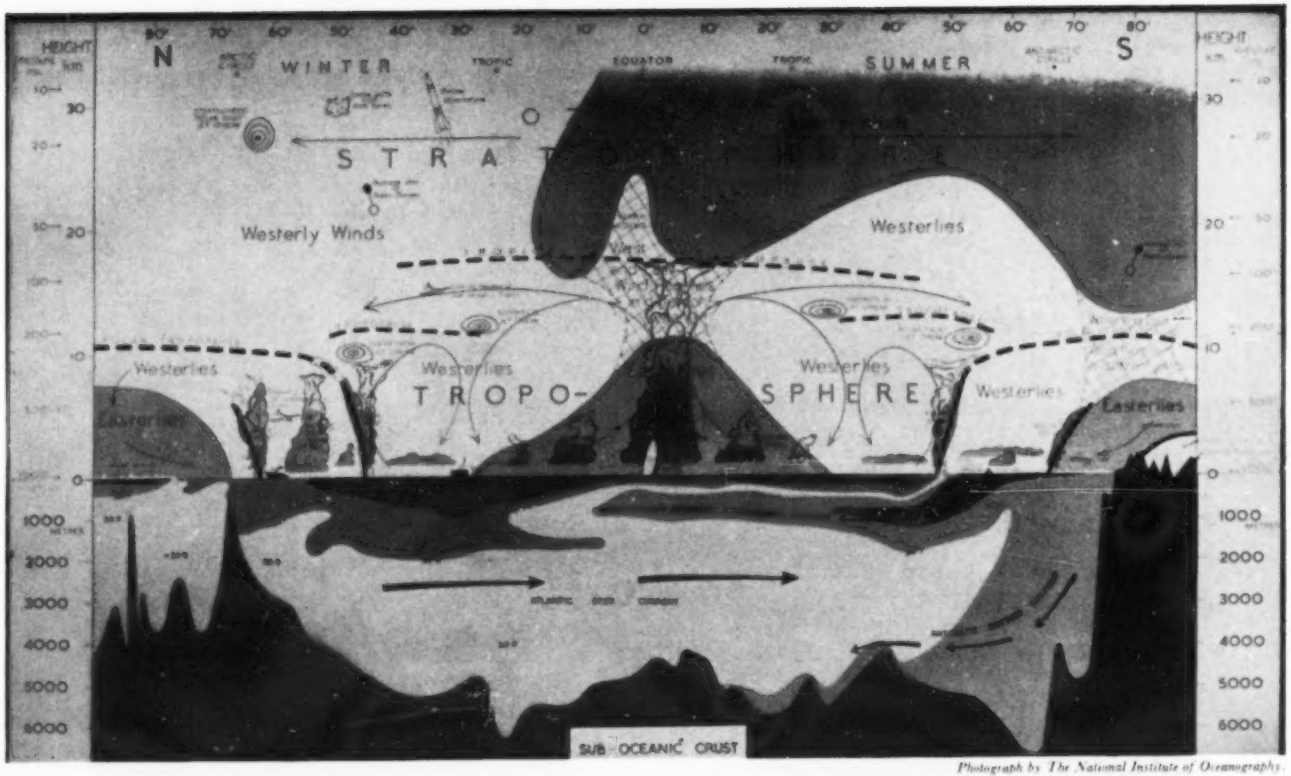
30 kilometres and through the entire depth of the ocean, taken near 30°W in most latitudes but at the northern end following the middle of the Norwegian Sea. This section passes rather near Jan Mayen, Iceland, the Azores and the eastern tip of Brazil, passes through the Weddell Sea and indicates the bedrock underneath the Antarctic ice-cap as revealed by the glaciological and gravitational work of the Trans-Antarctic Expedition. Colour (darker portions of Plate I) was used to distinguish regions of prevailing easterly wind components from the more general westerlies and also to distinguish different salinities in the ocean water. Arrows indicate the mean motions in the meridional and vertical plane, and it is seen how these motions are related to the characteristic weather of the different climatic zones.

The surface westerlies of limited extent seen on the section (Plate I) near the equator occur wherever the intertropical convergence (that is, the meteorological equator) is some distance from the geographical equator. The most extensive development of these westerlies is in the Indian south-west monsoon in the northern summer, where the intertropical convergence is displaced seasonally as far as 30°N. The mean latitude of the meteorological equator is several degrees north of the geographical equator.

High salinity of the ocean surface layers in the zones of descending air currents (arid zone) may be attributed to evaporation; nearer the equator the evaporation is compensated by rainfall. Low salinities characterize melt water derived from the polar ice. Salinity serves as a tracer by which the movement of water bodies may be followed. Some asymmetry between the northern and southern hemispheres is apparent in the fact that, in the longitude of the section, the southern sea ice extends, in the Weddell Ice Tongue, to latitude 59°S even in summer, whereas the northern ice in winter scarcely reaches the middle of the Norwegian Sea south of 75°N.

A prominent feature of the section is that, whereas the circulation in the main mass of the atmosphere repeats similar features in both northern and southern hemispheres, the ocean circulation in the Atlantic sector shows a net movement from south to north in the upper layers and a compensating net southward transport in the deep ocean. This appears to be attributable to a geographical accident. The warm equatorial current near the equator in the surface waters of the South Atlantic is fanned westwards (this expression is an oversimplification) by the south-east trade winds in just the right latitude to be divided by the "nose" of Brazil, from which point there is a steady loss of some of the surface water from the southern hemisphere to the northern—a supply of warm water which ultimately makes its way into the Gulf Stream. This is presumably a very sensitive point in the circulation mechanism of the Atlantic sector, since quite a small displacement north or south of the main wind and ocean current zones might have a large effect on the quantity of water diverted into the northern hemisphere from the equatorial current. This is probably one of the factors which tend to amplify climatic changes in the Atlantic sector and particularly in the North Atlantic.

The atmospheric cross-section is here repeated in diagrams (Figures 1 and 2) which show the mean isopleths of west-wind speed and dry-bulb temperature near 30°W in January and July. These diagrams display the seasonal shift north and south of the main features of the circulation in the troposphere and the great weakening of the northern circulation in summer.



Photograph by The National Institute of Oceanography.

PLATE I—SCHEMATIC MEAN CROSS-SECTION THROUGH THE ATMOSPHERE AND OCEAN FROM NORTH POLE TO SOUTH POLE IN JANUARY NEAR 30° W (AND MIDDLE OF THE NORWEGIAN SEA).

Symbols indicate observation methods and main features of the circulation; shading explained in text.

[*To face p. 320*

To face p. 321]

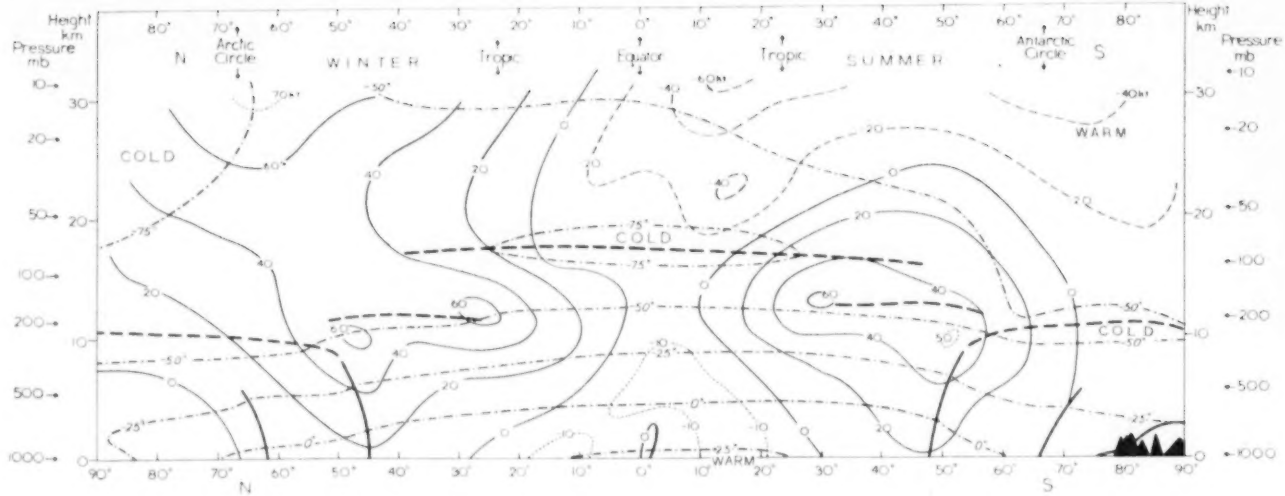


FIGURE 1—CROSS-SECTION SHOWING ISOPLETHS OF WEST-WIND SPEED (KNOTS) AND DRY-BULB TEMPERATURE (°C) NEAR 30°W IN JANUARY

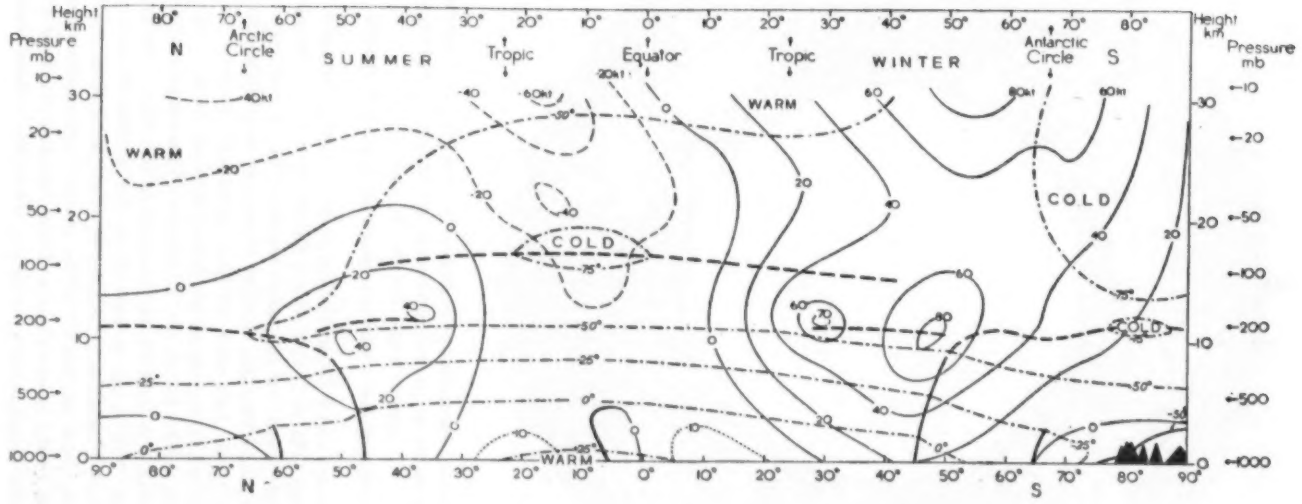


FIGURE 2—CROSS-SECTION SHOWING ISOPLETHS OF WEST-WIND SPEED (KNOTS) AND DRY-BULB TEMPERATURE (°C) NEAR 30°W IN JULY

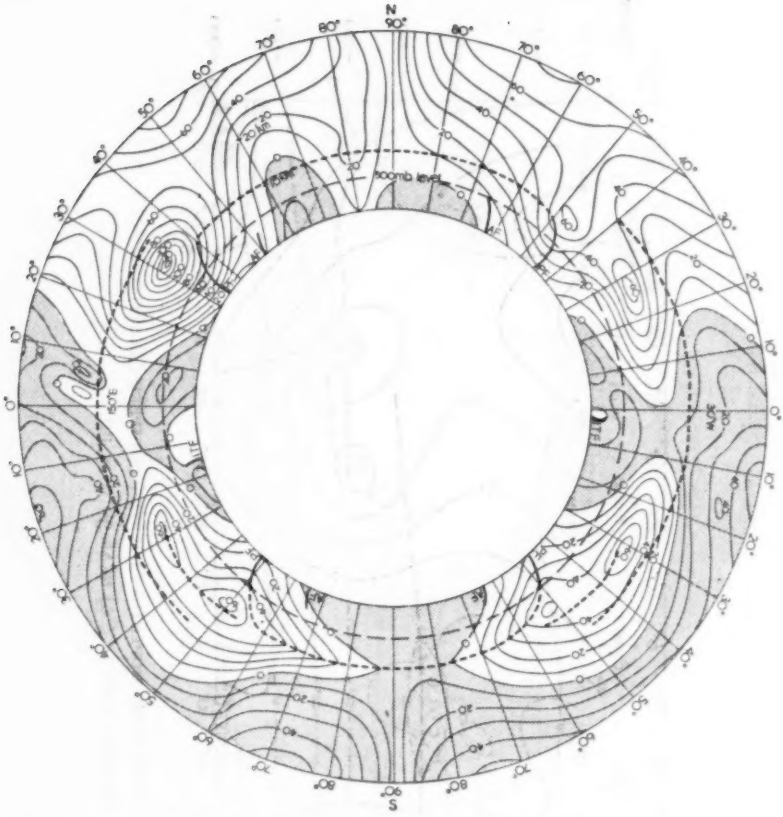


FIGURE 3—VERTICAL CROSS-SECTION BETWEEN NORTH AND SOUTH POLES IN 150°E AND 30°W FROM 0–30 KM HEIGHT SHOWING MEAN ZONAL WIND COMPONENTS (KNOTS) IN JANUARY

Prevailing east-wind regions are shaded; the height scale is linear.

The mean January and July circulation patterns in the troposphere were also depicted on globes (Plates II–V) which for the first time presented isopleths covering the whole world for the same period of years (the 1950s). This is a necessary scruple, since climatic changes of greater or lesser degree are always going on. Before 1950, data were far from adequate to cover the globe with mean values related to a homogeneous period of years. Even in the 1950s there is some conjecture involved over the far south and the southern Pacific. Nevertheless, it is important to establish the practice of adopting a uniform period of years everywhere. The levels portrayed on the globes are the surface and 500 millibars (5 to 6 kilometres), the latter as a sample (still the highest level for which data nearly cover the world) of the general circumpolar westerly winds which carry most of the momentum and are therefore the most fundamental part of the general atmospheric circulation. The globes show how this upper

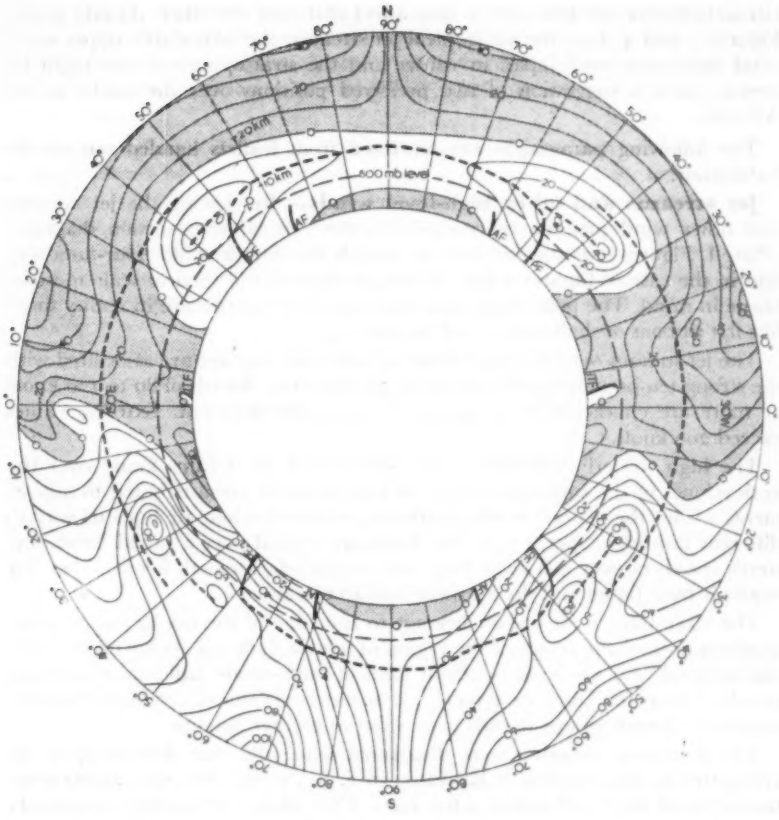


FIGURE 4—VERTICAL CROSS-SECTION BETWEEN NORTH AND SOUTH POLES IN 150°E AND 30°W FROM 0–30 KM HEIGHT SHOWING MEAN ZONAL WIND COMPONENTS (KNOTS) IN JULY

Prevailing east-wind regions are shaded; the height scale is linear.

wind flow is rather simply related to the largest-scale features of the surface thermal pattern. (In the troposphere westerly winds circulate around the cold polar cores, that in the hemisphere where it is summer being kept sufficiently cold by the persistent ice-cap which reflects and wastes most of the incoming radiation. By contrast, in the stratosphere in summer the ozone layer becomes warmest in the 24-hour sunshine over the polar region and hence the general summer picture is of easterly winds circulating around a warm polar core.) Perspex rings, or "collars", fitting round the globes in 30°W and 150°E (Figures 3 and 4) indicated the prevailing values of mean west-wind speed at heights other than those depicted by isopleths on the globes. Here it is important to notice that the equatorial zone of slack circulation, though extensive, is not so extensive as the 500-millibar pattern might suggest. Moreover, studies of the meridional circulation show that impulses across the equator (by which the

circulation over one hemisphere may affect that over the other) do take place. Figures 3 and 4 show the subtropical jet streams, the formidable upper west-wind maximum over Japan in winter and the stratospheric winter-night jet stream (with a suggestion of two preferred positions over the southernmost Atlantic).

The following paragraphs are reprinted from leaflets handed out at the Exhibition:

Jet streams and other high-level winds.—In viewing the jet streams and other wind maxima represented on the vertical cross-section diagrams (Plate I, Figures 1–4) the effect of the roughly two-hundredfold (four-hundredfold in the case of Figures 3 and 4) exaggeration of the vertical scale must be borne in mind. The polar-front and subtropical jet streams are in reality more like flat ribbons or shallow rivers of fast-moving air.

The jet streams over the polar fronts of either hemisphere are associated with the strong temperature gradients in the frontal zone. Speeds of 80 to 120 knots or more are characteristic at points of strong development. Extreme values exceed 200 knots.

The high westerly velocities in the subtropical jet streams found over the anticyclones of the subtropical belts of high pressure are attributed to adjustments within the general wind circulation, required when air finds its way to different latitudes. Speeds over 100 knots are typical over a broad band. Extreme speeds of over 300 knots have been reported over both hemispheres (for example over Japan and the southern Indian Ocean).

The stratospheric jet stream belongs to the zone of the strong temperature gradient around the fringe of the region of winter darkness (polar night). It is encountered near the present height limit of radio-sonde balloons; maximum speeds of 80 to 100 knots are typical and an extreme value of 225 knots has been observed, though greater speeds may occur at greater heights.

The Krakatoa easterlies were discovered when the dust thrown up to 30 kilometres by the eruption of Krakatoa (6°S, 105°E) in 1883 was carried westwards round the world within a few days. They blow very steadily, commonly at over 100 knots (extreme reported 140 knots). Their cause is little understood, but together with the lower tropical easterlies they represent the strongest development of the easterly winds blowing around the heated "core" of the stratosphere over the summer hemisphere.

The steady easterly winds in the lower stratosphere are quite weak near the polar region where the summer heating is strongest, owing to the 24-hour supply of solar radiation. Over tropical latitudes, however, these easterlies commonly exceed 50 knots and in the northern summer speeds up to 120 knots have been reported at heights of about 18 to 20 kilometres south of the heated plateaux of Asia.

A westerly wind current is found in some years, at least between Africa and the central Pacific, embedded at about 18 to 22 kilometres' height near the equator in the general stratospheric easterlies (Berson westerlies). These westerlies, so far unexplained, cover a rather narrow zone and are weaker and less steady than the usual easterlies; nevertheless they sometimes continue for several months.

Ozone.—Ozone is produced by photochemical action in the upper stratosphere at heights of about 20 to 50 kilometres, mostly over lower latitudes and in

higher latitudes over the summer hemisphere. The process absorbs ultra-violet radiation. The main concentration of ozone is found at heights between 20 and 30 kilometres. The general spread of this ozone towards higher latitudes and its subsidence in certain situations should tell us something of the circulation in the stratosphere.

The atmospheric circulation and the climates in which we live.—The layers portrayed in the cross-sections (Plate I, Figures 1 and 2), between the surface and a height of 30 kilometres (100,000 feet), contain about 99 per cent of the mass of the atmosphere. All weather phenomena, in the strict sense, take place within the troposphere, the upper limit of which (known as the tropopause) is shown at heights of about 9 to 18 kilometres over different parts of the world. The troposphere contains 70 to 90 per cent of the mass of air over a given point.

Our knowledge of the atmospheric circulation is continually being built up by observation and extended by new techniques. The network of observation points where wind, temperature, humidity, atmospheric pressure etc. are regularly measured is densest and most nearly complete at the earth's surface. Notable progress towards its completion has been made in the last 15 years or so: the first permanent observing stations on the Antarctic continent were opened by the British Falkland Islands Dependencies Survey in Grahamland in 1944, and the network has been extended to give a reasonable coverage of Antarctica in, and since, the International Geophysical Year in 1957–58. There are still a few lamentable gaps in the network, and corresponding gaps in our knowledge, over the great expanse of the South Pacific Ocean and in the tropics.

Voluntary observing ships amongst the merchant fleets of all nations supply observations from the oceans along the trade routes, and ocean weather ships maintain a constant weather watch at fixed positions away from the main areas frequented by shipping in the North Atlantic and North Pacific. An example of the coverage of the oceans by weather observations was shown at the Exhibition by the World Meteorological Organization Maritime Commission map of observations reported at 0600 GMT on 1 November 1959.

Coverage of the most remote ocean regions may some day be completed by floating robot weather stations, examples of which have already been in service south of Australia and north of the Soviet Union. Both Russia and the United States have operated observation camps on the floating ice in the central Arctic for long periods in recent years and the network of permanent observation posts on land now extends to the northernmost islands in 80°–82°N.

Upper air temperatures, pressures and humidities are measured by radiosonde and upper winds by radar techniques of following the sounding balloons. The average heights reached before the balloons burst are about 18 kilometres over the polar regions and 23 kilometres elsewhere. The network is sparse over the oceans and over the tropics. Aircraft observations add detail in the lower atmosphere, where cloud formations and weather phenomena also reveal the structure of atmospheric motions.

Our knowledge of the principal currents of the atmospheric circulation at greater heights is still fragmentary, derived from occasional observations of the smoke puffs from shell bursts and of temperatures etc. from rockets. At heights of 20 to 30 kilometres important clues have been obtained from the transport of "tracers" which move with the air—very fine volcanic dust particles,

atmospheric ozone and nuclear fission products from bomb tests (fall-out), all observable from the ground.

Air motion in the horizontal plane is controlled by a balance of forces due to pressure differences, the rotation of the earth, the curvature of the air's path and friction. As a result, over most parts of the world except near the equator the wind normally blows nearly along the lines of equal pressure (isobars) or along the contours of the constant-pressure surfaces, and these lines may be used as a convenient way of mapping the prevailing winds. The wind blows anti-clockwise around regions of low pressure in the northern hemisphere and clockwise in the southern hemisphere. The steepness of the pressure gradient, or of the gradient of an isobaric surface, gives an indication of the strength of the winds, though the wind strength also depends on the latitude and path curvature amongst other things.

On the globes (Plates II–V), following the usual convention, the pattern of prevailing winds near the surface is indicated by isobars of atmospheric pressure (reduced to sea level and standard gravity at 45°N to give a comparable datum), and the wind pattern in the middle and upper troposphere is indicated by contours of the 500-millibar constant-pressure surface. Representation by means of the topography of an isobaric suface has the advantage that the contour-spacings for any given "gradient" wind speed are independent of the air density at any particular level in the atmosphere. Contours of the 1000-millibar surface could be used to represent the patterns prevailing near the ground but, if the same height interval were used as at 500 millibars, the lines would be too few to show the pattern. To correspond to the 100-metre spacing of the 500-millibar contours on the globes, mean-sea-level isobars should be at intervals of about 12 millibars—equal horizontal distances between the lines would then correspond to the same "gradient" wind speeds as at the upper level.

Over much of the Southern Ocean the isobars of mean-sea-level pressure at 5-millibar intervals and the contours of 500-millibar topography happen to be about the same distance apart. This means that the prevailing westerly winds at the 500-millibar level (or about 5 kilometres) are roughly two-and-a-half times as strong as the prevailing winds just a little above the earth's surface at heights of about 500 metres (1,500–2,000 feet); nearer the surface, friction reduces the wind speed and, particularly over land, turns the wind to blow towards the low pressure.

In January, to which the main cross-section picture (Plate I and Figure 1) refers, the principal features of the atmospheric circulation are near their most southerly positions of the whole year. At that time the wind circulation over either hemisphere is of about equal strength, but in July (as shown in Figure 2 and Plate IV) the northern hemisphere circulation has weakened so much and become concentrated in such high latitudes that its total momentum is only about a quarter of that over the southern hemisphere.

Over most of the world at all levels the mean zonal (west–east) components of atmospheric motion far outweigh the mean meridional (north–south) components. This is a corollary of the zonal distribution of solar radiation received and the resulting thermal pattern. Air moving poleward as part of any convective transport, if it retains its initial absolute vorticity and angular momentum, acquires anticyclonic vorticity relative to the earth and a relative angular momentum which comes to light in a marked zonal component of

motion. Disequilibrium in the forces governing the horizontal motion of the air necessarily entails convergence or divergence, vertical motion, and meridional and cross-isobaric flow. Mean motions in the vertical and north–south planes (represented by arrows on Plate I) are smaller by several orders of magnitude than those in the west–east and horizontal planes; they are correspondingly more difficult to observe, and our knowledge of them is more uncertain.

The large-scale circulation of the air over the globe may be looked upon as a great convection system which transports heat from the surface in the lower latitudes to the regions where there is a net loss of heat in the upper troposphere and in high latitudes. The energy of the system is maintained through the agency of gravity because on average the regions where the air is heated are at a higher pressure and a lower mean altitude than the regions where it is cooled. In the stratosphere, it is true, there is another heat source region (in the ozone layer over equatorial regions and, even more pronounced, over the polar cap in the summer hemisphere) above the main cooling regions of the troposphere. For this very reason the stratospheric circulation is largely independent and only the lower layers above the tropopause become indirectly involved in the circulation of the troposphere.

Unequal heating of the lower air over different types of surface (ocean, ice, dry land, forest, swamp, mountain and so on) and, most of all, the inequalities of heating between different latitudes establish horizontal pressure gradients throughout the middle and upper troposphere. The high albedo (reflectivity) of snow and ice surfaces introduces a zone of sharp contrast of effective heating and of strong gradients near the snow and ice margin. Over warm regions the isobaric surfaces are lifted (vertical expansion of the air column) and over cold regions they are lowered (vertical contraction), and the air is set in motion. The thermal pattern, and in particular the coldness (and relatively high density) of the polar air, produces generally low pressure throughout a great depth of the upper troposphere (and above) over the cold polar regions, around which westerly winds prevail. A sample of this great flow pattern is represented on the globes by the contours of the 500-millibar surface, and up to 70 per cent or more of the mass of the atmosphere between heights of about 2 to 5 and 15 to 20 kilometres is involved in the "circumpolar vortices".

There are more or less prominent wave-like meanderings in the upper tropospheric westerly windstreams (most pronounced in the northern hemisphere), apparently determined partly by the geography of warm and cold surfaces in different parts of each latitude zone and partly by the dynamics of a current disturbed by passing over mountain barriers. The great meridional mountain chains of the Rockies and Andes and the high plateaux of Asia are particularly important in producing preferred longitudes for ridges and troughs in the contours of the pressure surfaces. These ridges and troughs, and the accompanying waves in the upper westerlies, however, shift their longitudes as the belt of strongest winds moves north and south with the seasons and as changes occur in the prevailing strength of the zonal windstream. The asymmetrical position of the centre of the Antarctic ice surface also tilts the whole southern hemisphere circulation towards the Indian Ocean side. Similar, though greater, eccentricity of the northern hemisphere circulation towards the Atlantic sector must have existed in the maximum phases of the Quaternary ice age.

The broad, deep current of westerly winds which dominates the scene in the

lower atmosphere over both hemispheres is concentrated in certain bands into what are called jet streams with windspeeds of 100 to 200 knots or more. There is a general level of maximum wind speeds near, or just below, the tropopause where the strongest thermal gradients in the lower atmosphere (as, for example, at and near the ice margin or the very mobile polar front) produce their greatest integrated effects.

Adjustments in the flow of the meandering westerlies, particularly in the levels of strongest wind, produce accumulations and divergences of mass which account for the anticyclones and depressions of the surface weather map and steer, or propagate, them generally from west to east around the world. High-pressure systems predominate along the warm flank (equatorial side) of the polar-front jet stream while the subpolar low-pressure belts in either hemisphere are associated with the cold side of the jet stream. This involves a mass transport across the jet stream aloft, which is partly compensated by a contrary motion in the surface friction layer. Through the surface pressure systems the familiar climatic zones and surface wind belts are explained.

The mean meridional circulation in the vertical plane, shown by arrows on Plate I, is in three main cells. The largest and best defined, and probably the steadiest, is a direct cell between the equator and about latitude 30°, often called the Hadley circulation, after G. Hadley who first suggested it in his account of the trade winds and counter-trades in 1735. This is a "direct" cell in which warm air rises near the equator and cooler air sinks in higher latitudes. Another, rather ill-defined and variable, "direct" circulation cell is observed over the polar caps. Middle latitudes are, however, dominated by an "indirect" vertical circulation cell in which the rising air is in the higher latitudes (near the polar front) whilst the warmer air in the anticyclone belt near latitude 30° subsides.

The subtropical jet stream, which attains slightly greater maximum speeds than the polar-front jet, is of the right magnitude to be explained largely by the angular momentum which the poleward-moving air in the upper part of the Hadley circulation cell brings with it from the lowest latitudes. However, the extreme speeds (*circa* 300 knots) are perhaps only reached in complex situations where the thermal gradient usually associated with the polar-front jet stream is also involved (coalescence of polar-front and subtropical jet streams). Cases of this kind occur over Japan (compare the normal winter situation near 40°N, 150°E shown in Figure 3) and Amsterdam Island (southern Indian Ocean), and more occasionally south of Newfoundland and over the Mediterranean.

Other aspects of the circulation introduce variations and modifications of our general picture as well as a complex embroidery of detail, smaller-scale circulations and turbulent eddies superposed on the grand-scale picture of the mean conditions. There is much to be learnt by studying the detail of how the heat, moisture and momentum in the atmosphere are transported and their balances maintained. The biggest modifications are those due to (i) the transport of evaporated moisture followed by recondensation in zones and regions where vast quantities of latent heat are liberated and (ii) the transport of heat by the ocean itself. Variations of both these items change the pattern of heating driving the atmospheric circulation and thereby change the pattern and the vigour of that circulation.

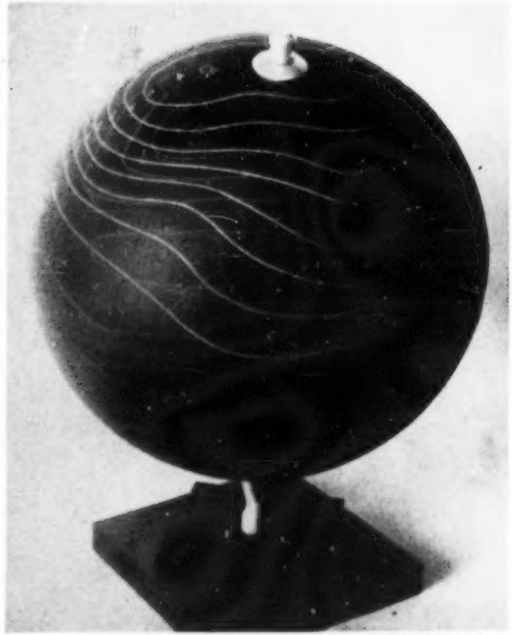


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PLATE II—NORTHERN HEMISPHERE VIEW ABOUT THE GREENWICH MERIDIAN: JANUARY

Note particularly the relationship between the positions of the surface features, Iceland low, Azores high etc. and the mean flow pattern about the 5 km level. Notice also the small size of the cold polar core of the upper circulation, though the shape of this core (positions of troughs etc.) impresses its influence upon the circulation over most of the northern hemisphere.

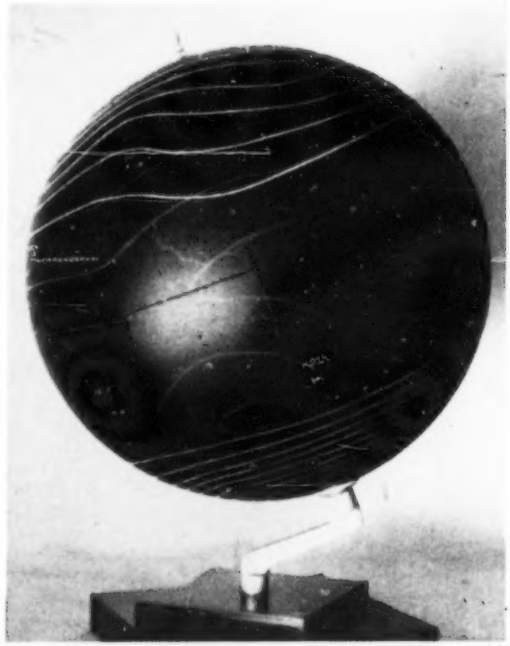

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PLATE III—EQUATORIAL VIEW ABOUT THE GREENWICH MERIDIAN: JANUARY

Striking features of this picture are:

(i) the broad area of the world in tropical and equatorial latitudes over which the mean gradients are weak right up to the 5 km level, though Figures 3 and 4 show that the region of slack circulation between the subtropical jet streams at greater heights is by no means so broad.

(ii) the relatively greater strength of the southern hemisphere circulation in this and neighbouring sectors even in the southern summer.

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GLOBAL PICTURES OF MEAN-SEA-LEVEL ISOBARS AND 500 MB CONTOURS FOR THE 1950S

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PLATE IV—NORTHERN HEMISPHERE VIEW ABOUT THE GREENWICH MERIDIAN: JULY

The northern hemisphere circulation is much weaker (weaker gradients) than in winter and the upper westerlies do not penetrate into such low latitudes. However, the polar core of the circulation is out of centre towards the east Canadian–Atlantic–European sector and hence, over much of this sector, the jet stream in July is no farther north than it was in January.

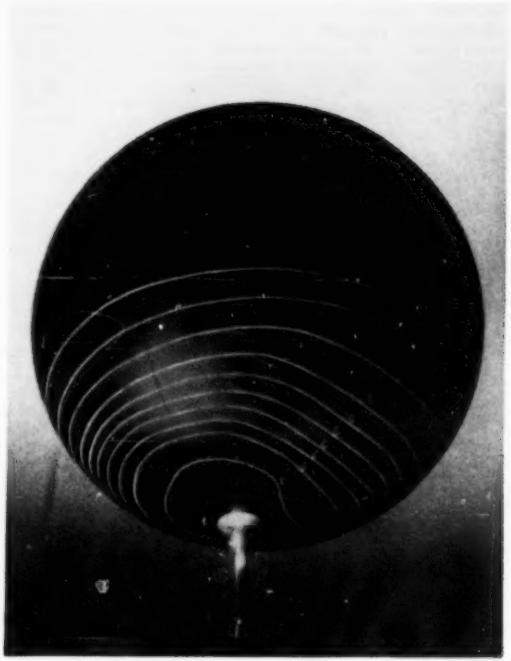

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PLATE V—SOUTHERN HEMISPHERE VIEW ABOUT 120°E: JULY

The southern hemisphere circulation is out of centre towards the Indian Ocean side (effectively a broad trough in that sector) and the gradients are strong over a much wider range of longitudes than is the case with the northern hemisphere winter circulation.

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The ocean surface currents are in the main wind-driven and hence the ocean and atmospheric circulations (and heat transports) are interlinked.

Variations of the atmospheric and oceanic circulations entail diversions of the prevailing windstreams and depression tracks, leading to spells of abnormal weather and changes of climate. There is much interest in building up a synoptic picture of these events—the dry or wet summers, the mild or severe winters with their inevitably great impact on human life—and attempting to trace back the shifts of the atmospheric circulation involved to their physical causes. In some cases it seems that an extensive area of warm or cold water on the ocean surface may distort the atmospheric circulation for several months, on account of the large heat capacity of the ocean and the great quantities of heat involved in reducing the anomaly. Such "slow-to-change" features and processes hold out some hope of forecasting the general weather characteristic of the ensuing season.

There are indications that a wider field of geophysics, and indeed of solar physics, may be involved in the long-term changes of weather and climate. Some quite long-lasting changes probably occur solely because of shifts in the complicated pattern of heat storage in the oceans, changes of reflectivity of the land surface due to ice or vegetation, changes in the carbon dioxide content of the atmosphere or other causes located near the surface of the earth and within the atmosphere or oceans. But the total quantity of radiation available to heat and drive the atmosphere may undergo variations over periods of years and centuries—for instance due to changes in the solar spectrum of emitted energy, or due to volcanic dust veils screening the earth or even tidal waves and tidal forces breaking up and dispersing some of the polar ice.

Since this article was written, the first series of daily charts of the circulation at the 10-millibar level (about 30 kilometres) have been published.[10] This level is of interest not only because it is the highest for which meaningful daily maps could be drawn with the special observational effort of the International Geophysical Year, but also because it is about the lowest level at which the independent circulation generated by the heating and cooling patterns of the stratosphere can be clearly seen and studied. It is the stratospheric circulation, particularly at (and above) the levels of most ozone, which may be expected to show some effects of the phenomena accompanying sunspots and solar flares. The lower stratosphere also partakes to some extent in this upper circulation, in which, therefore, 5 to 10 per cent of the mass of the atmosphere may sometimes be concerned. In some situations the possibility of interference with the main tropospheric circulation below may not be excluded.

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CLIMATOLOGICAL EDGE-PUNCHED CARDS

By R. E. BOOTH

Summary.—This article describes specially designed edge-punched cards containing monthly climatological data and notes together with synoptic notes and the predominant and persistent synoptic types occurring during a particular month. Some indication is given of their uses.

Description of card.—Edge-punched cards provide a convenient and cheap index system. Basically the card provides an area in which certain information can be entered, whilst the holes round the periphery, when

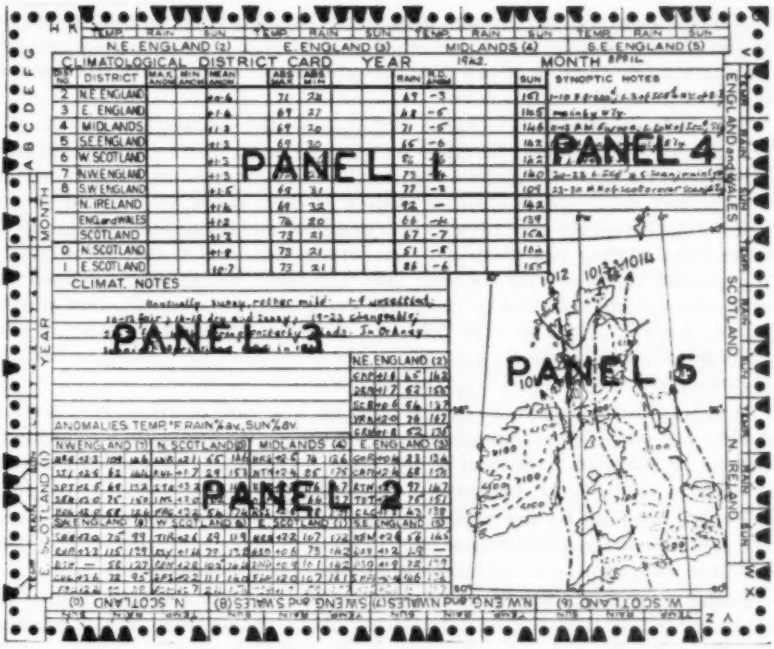

FIGURE I—CLIMATOLOGICAL EDGE-PUNCHED CARD FOR APRIL 1942

selectively slotted, provide a means of rapidly sorting out the cards required for a particular purpose. This sorting is done by passing a steel needle, like a knitting needle, through a particular hole in the pack and lifting it so that the cards with that hole unslotted are separated from the remainder.

Information on the cards.—Referring to Figure I, which shows the general lay-out of the card and the type of punching around the edges:

Panel 1 gives monthly anomalies of mean temperature, sunshine and rainfall for England and Wales, for Scotland and for Northern Ireland and also for various districts in the United Kingdom as defined in the *Monthly Weather Report*, together with the absolute maximum and minimum temperatures reported in each district during the month by any of the 500 odd co-operating observing stations. This table is largely a reproduction of the information contained in Table I of the *Monthly Weather Report*, but the anomalies have all been adjusted to refer to the same long-term averages (1921–50 in the case of temperature and sunshine and 1916–50 in the case of rainfall).

Panel 2 gives for each district the temperature, rainfall and sunshine anomalies at five well distributed stations on which the district values given in Panel 1 are based.

Panels 3 and 4 contain climatological and synoptic notes relating to the particular month. The climatological notes are compiled from the general description of the month's weather in the *Monthly Weather Report*; the synoptic notes are based on the *Daily Weather Report* and give a summary of the synoptic developments during the month over north-west Europe.

Panel 5 shows a mean pressure map for the month, similar to that published in the *Monthly Weather Report*, and superimposed on it a percentage of average rainfall map for the month based on that published in the appropriate number of *British Rainfall*.

The index system.—The names of the various districts appearing in Panel 1 are also arranged round the edges of the card, each district being allocated three holes for each of the three elements, temperature, rainfall and sunshine. The corrected monthly anomalies of each of these elements recorded in the body of the card have been divided into quintiles, and the appropriate group of three holes relating to a particular element and district is slotted according to the quintile into which the anomaly falls. The three sorting-holes provided for each element are sufficient to cover five categories; for example, very warm, warm, normal, cold and very cold, to use a convenient description of the quintiles of temperature. One or two of the three holes are slotted in various prearranged orders to cover the categories.

A series of holes are allocated for slotting the year and month on the card for evident reasons. The remaining holes around the top left and bottom right-hand corners provide for a selection of the cards according to defined periods of synoptic types, using H. H. Lamb's[1] classification.

Period covered by the cards.—In the first instance it is planned to cover the period from the present time back to January 1900, and much of this task has been completed. Current data will be added as a routine.

Some suggested uses for the cards.—The cards may evidently be used as a ready method of obtaining information about the weather of a particular month in the past, and also for the selection of those months in the period covered having similar anomalies or similiar predominant synoptic types to those of the current month. The selection of analogues to a particular month is also facilitated by this method of sorting. The information could, of course, be gained by a search through existing publications but only with considerably more expenditure of effort. Besides these simple uses of the cards one can speculate on various others once a sufficient period is covered. For example, they might be used to answer, for any district, such questions as "Have dry Aprils been more frequent in recent years than formerly?" or "What is the probability of a sunny June following a sunny May?" or possibly such questions as "Has severe winter weather tended to occur later in the season in recent years than it did earlier in the century?" or "What have been the predominant weather types in very cold Januaries?" Time will doubtless show an almost endless variety of uses to which these cards can be put.

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A NOTE ON AN UNUSUAL FALL IN HUMIDITY ON THE EQUATOR

By H. W. SANSOM, M.A., Ph.D., D.I.C.

On the morning of 11 March 1959 the relative humidity at Entebbe on the north-west shore of Lake Victoria fell suddenly from 98 per cent to below 50 per cent in about 15 minutes. Such a marked change of relative humidity would

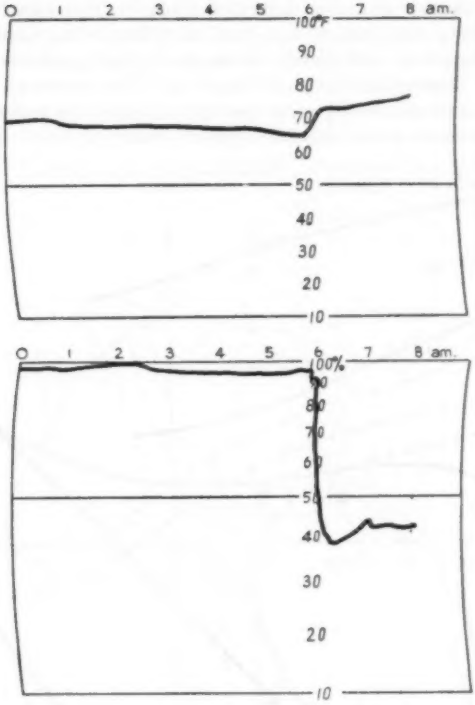

FIGURE 1—THERMOHYGROGRAM FOR ENTEBBE ON MORNING OF 11 MARCH 1959

be surprising at any time, in the absence of a well defined surface front, but the remarkable feature of this incident is that it was associated with an appreciable rise in surface temperature, and yet occurred at about 0620 hours East African Standard Time (0320 GMT), almost half an hour before sunrise. A reproduction of the trace from a combined thermohygrograph is shown as Figure 1. Simultaneously with the change in temperature and relative humidity, the wind, which had been virtually calm, increased to over 15 knots from a definite easterly direction. The hourly observations taken from the Entebbe Airport observation book were as follows:

Time *E.A.S.T.*	Wind *knots*	Dry bulb °F	Dew-point °F	Relative humidity %
0500	Calm	68·0	67	98
0600	Calm	66·5	65	98
0700	ESE 18	75·4	53	47

The sudden change in wind suggests the onset of the lake breeze but this does not normally occur before 1000 hours E.A.S.T. when solar heating has raised the land temperature above that of the lake, whereas on this occasion the wind set in before sunrise when the air temperature was still quite low. Furthermore, the wind direction associated with the lake breeze is almost invariably southerly, but in this case it was definitely easterly.

The incident occurred during a spell of unusually fine weather over most of British East Africa, the general low-level windflow being easterly and rather diffluent (see Figure 2) and clearly dominated by an anticyclone over Arabia and a tropical depression south of Mauritius. The low-level diffluence over western Kenya and eastern Uganda was undoubtedly also assisted by a marked fall in surface pressure over northern Uganda, which occurred during the night.

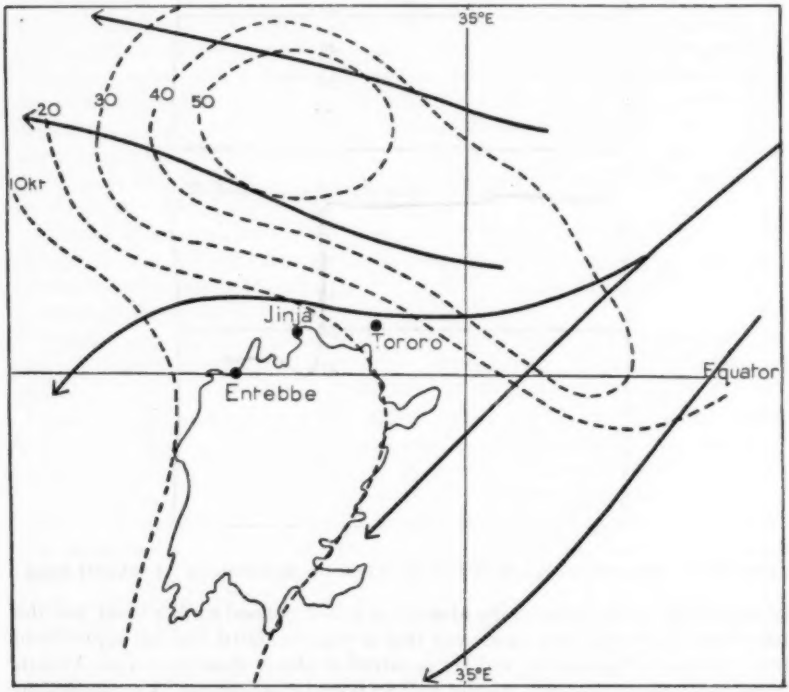

FIGURE 2—STREAMLINES AND ISOTACHS AT 6000 FEET ABOVE MEAN SEA LEVEL, 11 MARCH 1959

The sky over and around Lake Victoria had been almost clear during the previous day and during the night, with only one okta of cumulus reported most of the time. A comparison of the radio-sonde ascents at Entebbe for 10 and 11 March (made at 0600 GMT) showed that a considerable amount of subsidence had occurred by the time the later ascent was made.

As a result of the markedly diffluent low-level airflow in the neighbourhood of Lake Victoria there was a strong horizontal divergence centre situated just north of the equator on the meridian of 35°E. Figure 3 shows the result of a convergence/divergence analysis using Forsdyke's technique.[1] The units used are knots per degree. Under the existing easterly airflow, subsiding air from this centre of divergence was advected towards Entebbe. During the night, however, Entebbe itself was situated in an area of weak low-level convergence, due presumably to the off-shore nocturnal land breeze which sets in as the result

of differential cooling between land and lake. Under the influence of this land breeze the humidity at Entebbe had risen to near saturation. The sudden collapse of the land breeze clearly could not have been due to surface heating, and its collapse must therefore have been the result of the rapid advance of the "front" formed between the dry subsiding air from the east and the moist weakly rising air from the nocturnal land breeze. This supposition seems to be borne out by the fact that although there was apparently also a fairly sharp drop in relative humidity during the night or early morning at two other meteorological stations (Jinja and Tororo) near the northern shore of Lake Victoria, stations further inland gave no evidence of any sudden influx of dry air.

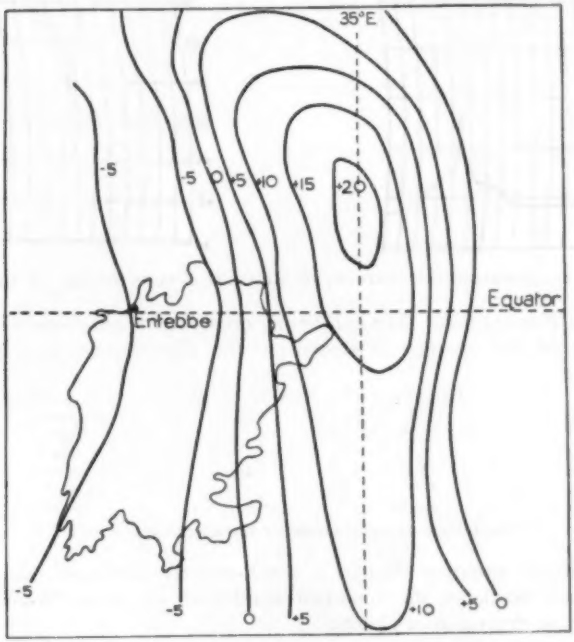

FIGURE 3—DIVERGENCE ANALYSIS OF WINDFLOW AT 2000 FEET ABOVE GROUND LEVEL, 11 MARCH 1959

Unit: knots per degree latitude

The phenomenon described was without known precedent in the meteorological records of East Africa, and it is all the more remarkable, therefore, in that it was repeated (though the drop in humidity was not quite so sharp) under generally similar conditions at about the same time on the following day.

Acknowledgements.—I am grateful to the Director of the East African Meteorological Department for permission to publish this note, and to my colleagues in the Department for their views and comments on the phenomenon described.

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EXCEPTIONAL TEMPERATURE AND HUMIDITY FLUCTUATIONS AT TURNHOUSE

By D. GIRDWOOD, M.A.

An exceptional variation of temperature and humidity occurred at Turnhouse (Edinburgh) on the afternoon of 10 May 1960. At 1348 GMT the temperature was 59°F. It then rose sharply to a maximum of 70°F around 1500 GMT, falling

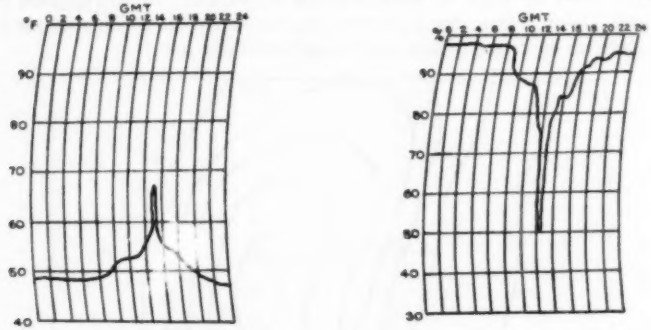

FIGURE 1—THERMOGRAM AND HYGROGRAM FOR TURNHOUSE, 10 MAY 1960

again to 54°F at 1515 GMT. The half-hourly observations are given below but the abruptness of the changes is shown on the thermogram and hygrogram (Figure 1).

	Temperature	Relative humidity	Wind	
GMT	°F	%	degrees	knots
1348	58·6	71	040	16
1420	59		080	16
1450	66·6	49	060	12
1515	62		060	9
1550	53·6	82	050	13

The maximum temperature for the afternoon was 70°F.

The synoptic situation showed a south-easterly airstream over northern England and Scotland, the 2000-foot wind from the noon Shanwell ascent being 120–130 degrees 20–25 knots.

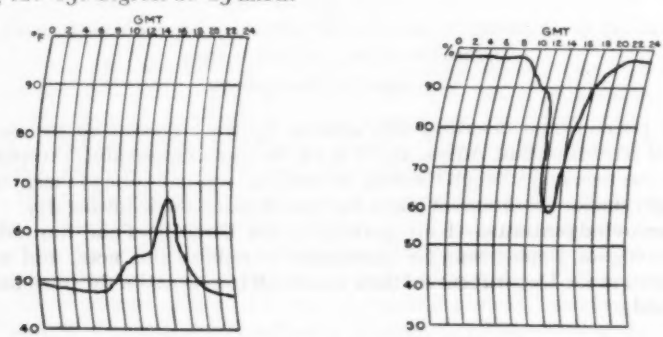

FIGURE 2—THERMOGRAM AND HYGROGRAM FOR MID CALDER (55° 53½′N, 03° 31½′W), 10 MAY 1960

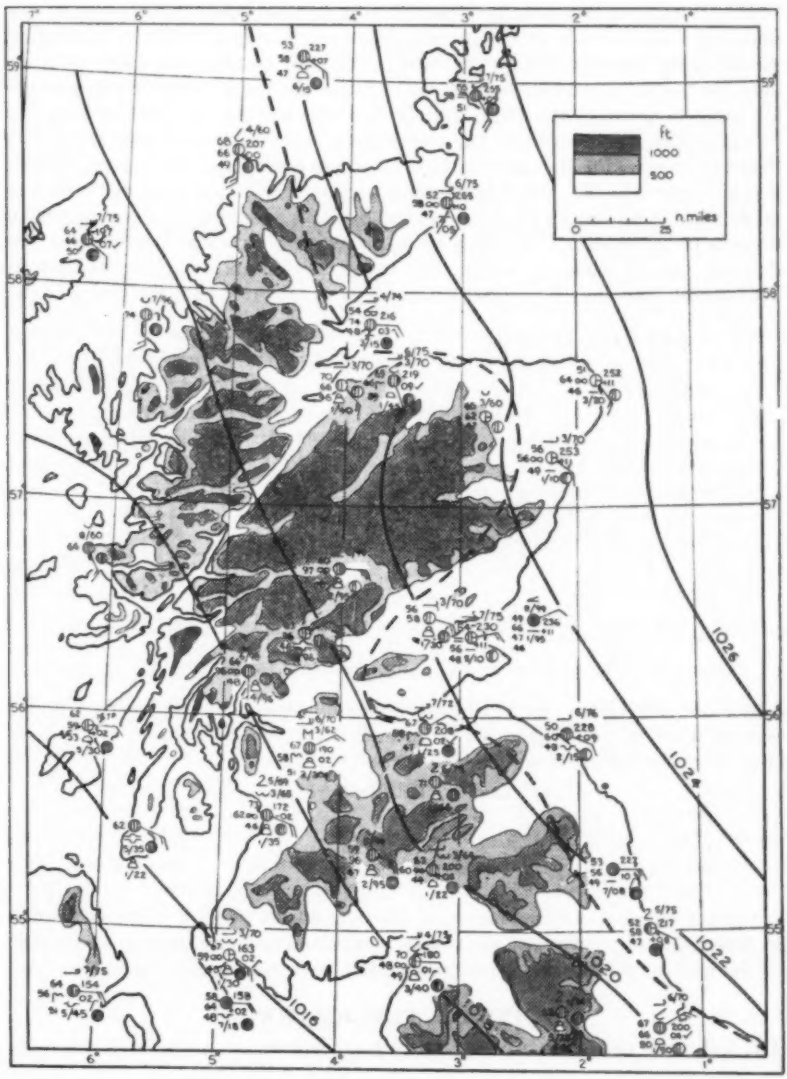

FIGURE 3—SYNOPTIC CHART FOR 1500 GMT, 10 MAY 1960

The autographic records from Mid Calder (Figure 2), 7½ miles south-west of Turnhouse, show a very similar though slightly less pronounced occurrence.

This instance is the most pronounced of a number which have come to our notice at Turnhouse, in south-easterly airstreams, and is particularly interesting as indicating the sharp boundary which can exist between the cool moist air over the North Sea and eastern coastal districts and the air modified by passage for some hours over the land, and in this case heated by descent from the Pentland and Moorfoot hills. The broken line on the 1500 GMT chart (Figure 3) shows the approximate boundary between these two surface air masses, though it is not suggested that this diurnal temperature "front" is so sharply defined in other parts of Scotland as it is in the Firth of Forth area where local topography favours its persistence. On 10 May a 40-degree wind-shift from 040 to 080 degrees was sufficient to permit the temporary influx of warm dry air at Turnhouse; this was followed by a backing to 060 degrees with the return of the

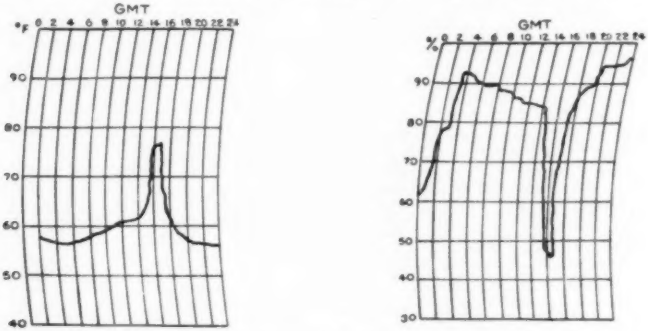

FIGURE 4—THERMOGRAM AND HYGROGRAM FOR TURNHOUSE, 5 JUNE 1960

cold moist air. Other instances have generally been associated with a larger veer of wind to 110 degrees or more and have persisted longer. On 5 June (Figure 4) the following sequence of events occurred:

	Temperature	Relative humidity	Wind	
GMT	°F	%	degrees	knots
1450	63	73	050	15
1550	76	46	110	12
1650	77	43	110	15
1750	63	76	040	14

Sudden changes of temperature of this magnitude, perhaps 10 to 14 degrees in fifteen minutes, in relatively steady wind conditions are readily noticeable to the general public, and have occasionally been commented upon.

OFFICIAL PUBLICATION

The following publication has recently been issued:

Quarterly surface current charts of the eastern North Pacific Ocean.

The last of a series of five atlases giving a world-wide coverage of the ocean current circulation has been published by the Marine Division of the Meteorological Office.

The new atlas, numbered M.O.655, and entitled *Quarterly surface current charts of the eastern North Pacific Ocean*, covers the area north of the equator and

from 160°W to the coast of the Americas. It is uniform with others of this well known series and is made up of quarterly charts of: (*a*) surface current roses, (*b*) surface current predominant direction and average rates and (*c*) surface current vector means.

These charts have been compiled from observations of surface currents sent to the Meteorological Office by voluntary marine observers in British merchant ships and from observations made in H.M. ships forwarded by the Hydrographer of the Navy. The observations cover the period 1855 to 1952.

NOTES AND NEWS

Adoption of the Celsius scale of temperature within the Meteorological Office

It has been decided to adopt from 1 January 1961 the Celsius scale of temperature for all temperature measurements, including "surface" observations, made for internal use within the Meteorological Office and for international purposes. Most readers will know that the Celsius scale has been used in the Office since 1 January 1956 for upper air observations.

The decision to change to degrees Celsius follows from a Resolution of Third Congress (1959) of the World Meteorological Organization expressing, amongst other things, the hope that Members who do not use the Celsius scale would adopt it for use in coded messages before Fourth Congress meets in 1964. For the Office to have gone over to the Celsius scale only in international synoptic reports would have involved unacceptable extra work, loss of time and risk of error in recutting teleprinter tape at the Central Forecasting Office for the international transmissions.

Thus all synoptic reporting stations controlled by the Meteorological Office including the auxiliary reporting stations will transmit temperature observations in degrees Celsius from 1 January 1961. The voluntary climatological stations will continue to use the Fahrenheit scale. Temperatures will be published in the Celsius scale in both the *Daily* and *Monthly Weather Reports*. The *Daily Aerological Record* has, of course, used that scale since 1 January 1956.

There will be no change in the temperature scales used for forecasts and weather reports for the public which will continue to use the scale with which the recipient is most familiar. Thus the forecasts for the general public, broadcast by sound radio and television and published in the Press, will continue to state temperature in degrees Fahrenheit while those issued for aviation will naturally continue to use degrees Celsius.

Detailed instructions have of course been issued to all those whose work is affected by the change.

Definition of "ground frost"

Since 1906 "ground frost" has been recorded by meteorological observers when the thermometer on the grass has fallen to or below 30°F (30·4°F for thermometers read to tenths). The reason for the introduction of the practice in 1906 has not been found, despite extensive search. The first publication of a reason appeared in the second (1930) edition of the *Meteorological glossary* where it is stated that injury to the tissues of growing plants is not caused until the temperature has fallen appreciably below the freezing-point of water.

The introduction of the Celsius scale of temperature into Meteorological Office practice for all internal purposes has led to a reconsideration of the definition of "ground frost". It has been decided that the explanation given in the *Meteorological glossary*, supposing it is correct, does not justify the continued use of the definition because the occurrence of "ground frost" is of importance to a larger proportion of the community, for example, in connexion with motor transport, than it was over fifty years ago. Therefore it has been decided that the practice of attaching special significance to the attainment of a grass minimum temperature of 30°F (or 30·4°F) or below by terming these "ground frosts" should no longer be continued.

Hence, on and after 1 January 1961, grass minimum temperatures will continue to be collected as hitherto. However, in publications the term "ground frost" will no longer be used and present statistics such as "Number of days with ground frost" will be replaced by "Number of days with grass minimum temperature 0°C or below". On the other hand, it will be convenient to retain the term "ground frost" for use in forecasts, and when so used it will imply a grass minimum temperature at or below 0°C (or 32°F).

OBITUARY

Mr. Harold Redhead.—It is with deep regret that we learn of the death on 19 October of Mr. H. Redhead, Experimental Officer, at the age of forty. He joined the Office in June 1947 as a Meteorological Assistant, and all his service was spent at aviation outstations. At the time of his death he was serving at Linton-on-Ouse. He is survived by a widow and two daughters to whom the sympathy of all who knew him is extended.

METEOROLOGICAL OFFICE NEWS

Retirement.—The Director-General records his appreciation of the service of:

Mr. D. K. Fraser, Senior Experimental Officer, who retired on 16 October 1960 on medical grounds because of failing eyesight. He joined the Office as a Clerk Grade III in August 1928. The greater part of his service has been spent at aviation outstations and Army units, with short spells in 1935 and 1936 at Kew Observatory and in the Forecast Division at Headquarters, respectively. For a time before his retirement he was associated with the meteorological side of civil aviation examination work at the Ministry of Aviation. During the Second World War he was three times mentioned in despatches.

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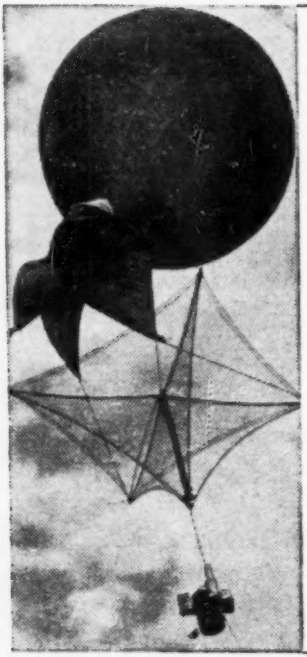

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Handbook of Statistical Methods in Meteorology. By C. E. P. Brooks, D.Sc. and N. Carruthers, B.Sc. (M.O. 538. 1953) 8vo. 25*s.* (post 1*s.* 5*d.*)

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